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ROOF TILES PREPARED BY USING FLY ASH AND ANALYZING MECHANICAL PROPERTIES

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ABSTRACT

CO_2 emissions from buildings and construction rose by nearly 1% per year between 2010 and 2016; releasing 76 Gt CO_2 in cumulative emissions. India is amongst the major producer of Fly ash, 57% of total power obtained from combustion of pulverized coal. By the end of the year 2020, the production of fly ash is going to cross 350 million tones. In order to utilize this fly ash that is considered as a waste in the manufacturing of roof tiles replacing the traditional clay and feltspar. The roof tiles with 30 wt %fly ash were prepared and its mechanical properties were studied.

***KEYWORDS:** Fly Ash, Utilization of Fly Ash, Waste Material, Environment & Mechanical Properties*

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Original Article

INTRODUCTION

The combustion of Pulverised coal yields fly ash as waste at thermal power stations. High ash content is found to be in the range of 30% to 50% in Indian coal [1]. The fly ash tiles are with high technical performance such as abrasion resistance, modulus of rupture and resistance to chemical attack along with dense products and low porosity [2-4].

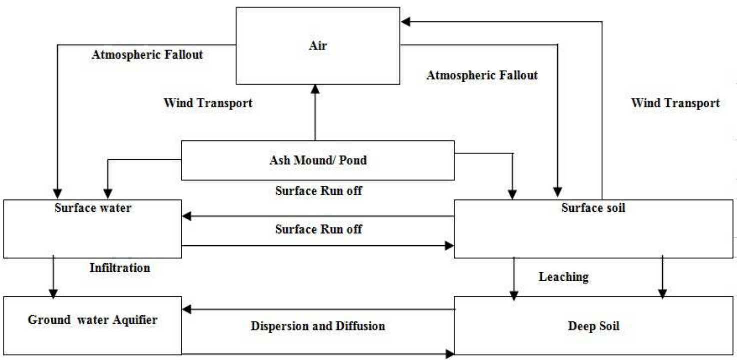

Figure 1: **Schematically Path Ways of Pollutant Movement Around Fly Ash Disposal [5]**

These tiles are imitations of stones such as sandstone, travertine, marble, and granite etc. The tiles made of fly ash are commercially used because of improved mechanical properties and aesthetic appearance. Environment pollution has to be reduced so as to decrease global warming. Fly Ash particles ranging in size from 0.5 to 300 micron in equivalent diameter pollute the environment [6]. About 95-99% of total constituent the major

constituents of Fly Ash and 0.5- 3.5% are minor. Oxides of Si, Fe, Ca, Al, and Mg is major and minor constituents are Ti, Na, K, and S. Fe_2O_3 and TiO_2 are kept to a minimum in order to avoid color. The raw material is selected from a group of plastic and non-plastic minerals. The first group contributes to strength development of green tiles clayey minerals such as kaolinite, illite, montmorillonite, etc. The second group is flux that consists of feldspar, felspathoids, quartz, pigmatite and quartzites. The alumina content of the composition affects chemical composition on microstructural and mechanical properties of fly ash tiles [7]. The flexural strength was raised from 80 to 150 MPa by addition of alumina to the fly ash tiles [8]. Fly ash is a by-product of thermal power plants resulting from the combustion of pulverized coal in the coal furnaces. The annual generation of fly ash in India is around 90 million tonnes out of which only 10% is used and rest being disposed of causing serious environmental problems [9]. The use fly ash as a raw material for the ceramic industry has been done in which the major constituents are SiO_2, Al_2O_3 and Fe_2O_3 with some minor constituents such as CaO, MgO and TiO2, and thus may be considered as low-cost resource materials for alumino-silicates. [10]. Uses of fly ash in tiles are reported in the literature [11–14]. The mechanical properties and the effects of fly ash incorporation in roof tiles revealed improvement in the scratch hardness and strength of the tiles [15, 16]. The high traverse strength of 72MPa for tiles and excellent thermal shock resistance by the sintering mechanism of tiles containing 60–75% fly ash in the temperature range of 1000–1080^{0}C. A controlled amount of fly ash addition improves the mechanical properties of ceramic tiles [17]. The present study was carried out to use fly ash as a source of alumino-silicate compounds to develop roof tiles. The study of mechanical properties was done.

EXPERIMENTAL PROCEDURE

The fly ash as a raw material was collected from one of the plants of Central India, a highly plastic clay, feldspar and calcined quartz. The chemical composition of the raw materials was carried out by conventional wet analysis methods. The standard batch composition used as reference consisted of 50 wt% kaolinitic clay minerals, 30 wt% feldspar, 15 wt% quartz, 5 wt% of other additives and designated “FAT1”. The other batches were prepared using 5, 10, 15, 20, 25, 30, 35 and 40 wt% fly ash by substituting kaolinitic clay and named FAT2, FAT3, FAT4, FAT5, FAT6, FAT7, FAT8 and FAT9 respectively. Every batch was wet milled with a dispersing agent for 6 hours. Coloring pigments were added during wet milling in separate batches to produce coloring effects. The slurry obtained after milling was spray dried and compacted into the desired shapes using the uniaxial pressure of 300 kg/cm^2. To get the “salt and pepper” effect, granules of different colors were mixed before compaction. The shaped samples were air dried then fired at 1300^{0}C for 50 minutes in the air. The rate of heating was kept at 10^{0}C/minute.

RESULTS AND DISCUSSIONS

The chemical analysis of the raw materials is given in Table 1.

Table 1: Chemical Analysis of Raw Materials

Constituents (wt%)	Fly ash	Clay	Feldspar	Quartz
SiO_2	63	52.5	65.2	98.2
Al_2O_3	24	26.3	19.4	0.3
Fe_2O_3	3.6	1.9	0.2	0.1
TiO_2	1.4	0.6	0.2	Trace
CaO	2.7	3.6	0.2	0.1
MgO	1.3	–	0	–
Na_2O	–	0.2	4.3	–

Table 1: Contd.				
K_2O	–	0.4	9.8	–
L.O.I.	3	14	0.5	–

Table 2: Quantitative Phase Analysis of Fly Ash

Phases	Volume %
α- Quartz	17.1
Mullite	21.4
Magnetite spinel	3.1
Hematite	1.2
Glass	57.2

The Fe_2O_3 and other impurities present in fly ash are low. The low carbon content (<2.07%) in the composition is considered suitable for the ceramic application. The chemical composition of the porcelainized stoneware tiles is given in Table 3.

Table 3: Chemical Composition of Roof Tiles

Constituents (wt %)	FAT1	FAT2	FAT3	FAT4	FAT5	FAT6	FAT7	FAT8	FAT9
SiO_2	68.3	68.5	68.9	71.0	71.2	71.6	71.8	72.2	72.5
Al_2O_3	20.9	20.9	21.0	21.1	21.1	21.2	21.3	21.2	21.5
Fe_2O_3	0.6	0.7	0.7	0.8	0.8	0.8	0.8	0.9	1.0
TiO_2	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.6
CaO	1.6	1.5	1.5	1.5	1.5	1.5	1.5	1.4	1.4
MgO	1.1	1.1	1.1	1.0	1.0	1.1	1.1	1.0	1.0
Na_2O	2.8	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.6
K_2O	2.1	2.1	2.0	2.0	2.1	2.1	2.1	2.0	2.0
ZrO_2	1.6	1.6	1.6	1.7	1.7	1.6	1.7	1.7	1.6

The result of quantitative XRD analysis of the fly ash is summarised in Table 2. Around 40% phase is crystalline, 57% is glassy and 3% unidentifiable. Among the crystalline phases, mullite and quarts are a major phase. The chemical composition of fly ash based tiles can be compared with that of commercial vitrified stoneware tiles. It can be observed from the table that SiO_2, Al_2O_3 and Fe_2O_3 increase with fly ash content. Figure 2 to 7includes the physico-mechanical properties of both green and vitrified tiles in relation to fly ash content. The water absorption decreased with the increasing fly ash content attaining minimum value in FAT7 composition and then increased (Figure 2). A gradual loss in flexural strength of green tiles was observed with the increasing fly ash content (Figure 3). This is due to the non-plastic behavior of fly ash, which is substituting for the plastic clay. The bulk density (Figure 4) increased with the fly ash content and reached maximum (2.47 gm/cc) in FAT7.

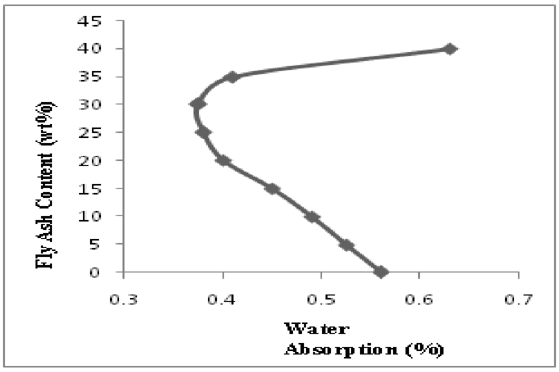

Figure 2: Variation in Water Absorption of Tiles in Relation in to Fly Ash Content

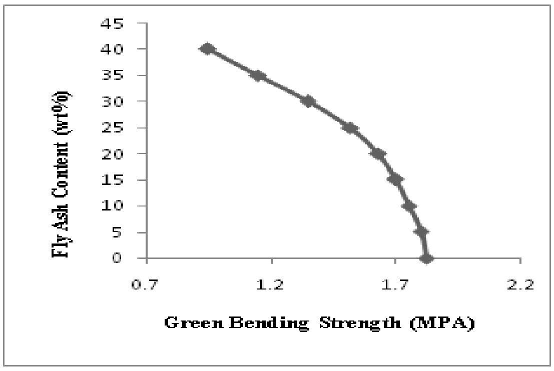

Figure3: Variation in Green Bending Strength to Tiles Relation to Fly Ash Content

The decreased in density in FAT8 and FAT9 is due to the reduced rate of sintering with the same reason as explained for reduced shrinkage. This is again due to the same reason, where the reduced rate of sintering in FAT8 to FAT9 composition caused the presence of more pores in tile body. However, FAT1 to FAT7 compositions had sufficient strength for handling while, FAT8 and FAT9 compositions had the very low strength and thus the rate of rejection was very high during handling. The compressive strength

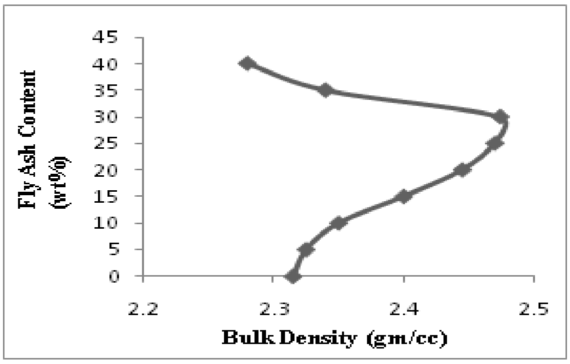

Figure 4: Variation in Bulk Density of Tiles in Relation to Fly Ash Content

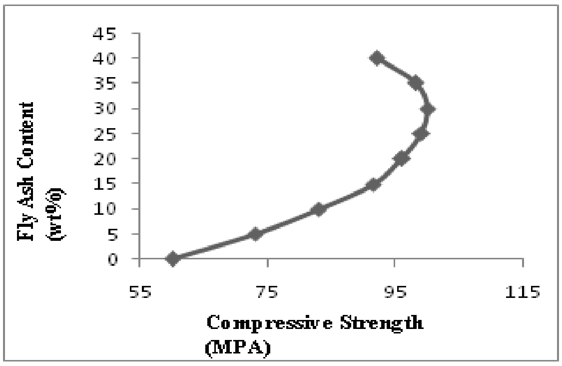

Figure 5: Variation in Compressive Strength Tiles in Relation to Fly Ash Content

(Figure 5) were increased with fly ash and found the maximum in case of FAT7 composition while, Young's modulus

(Figure 6) and abrasion resistance (Figure 7) were maximum in FAT7 composition. A linear relationship between bulk density, bending strength, Young's modulus and abrasion resistance was found. To understand the mechanism of strength development with increasing fly ash content, quantitative phase analysis of the vitrified tiles was carried out and the results are summarised in Table 4. Although the quantity of SiO_2 and Al_2O_3 are more or less equal in all the compositions, the quantity of the phases is varying with fly ash content.

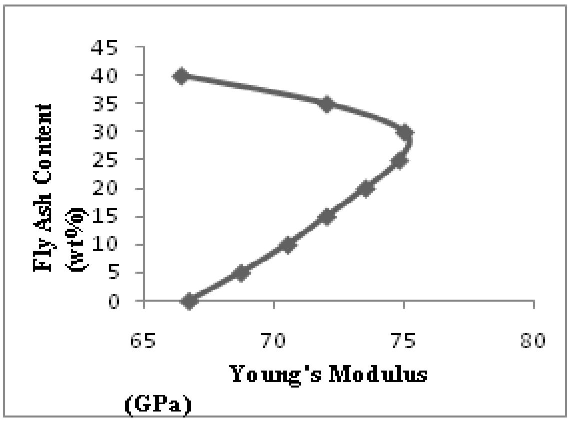

Figure 6: Variation in Young's Modulus of Tiles in Relation to Fly Ash Content

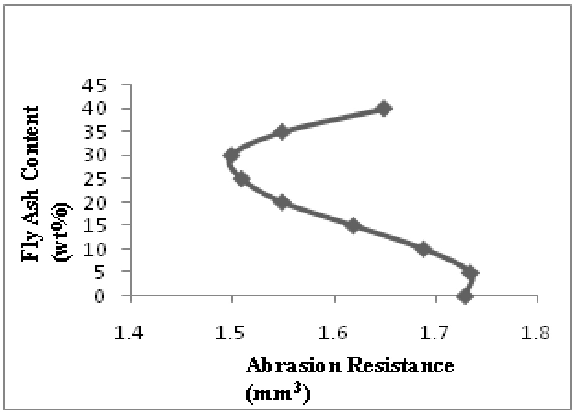

Figure 7: Variation in Abrasion Resistance of tiles in relation fly ash content

The mullite quantity roughly corresponds to 30–60% of the quantity, which could have been potentially formed on the basis of available alumina in the composition. The mullite content increased with fly ash and reached a maximum in FAT6 and FAT7 composition. The steady increase of mullite content up to FAT7 may be due to mullite, which was originally present in fly ash increasing with the increasing fly ash additions. Also, the presence of secondary mullite in the composition might have helped in the formation of primary mullite by reaction of SiO_2 and Al_2O_3 during the sintering process. In FAT8 and FAT9 compositions, the decreased mullite content was balanced by an increase in glass phase formation. The quartz content is almost constant for compositions FAT1 to FAT5. Thereafter it appears to decline. The glass content is increasing slightly, suggesting a reaction between added quartz in the batch and the fly ash.

Table 4:Quantitative Phase Analysis (vol. %) of 13000C Fired Fly Ash Tiles in Relation to Fly Ash Content

Constituents	FAT1	FAT2	FAT3	FAT4	FAT5	FAT6	FAT7	FAT8	FAT9
Mullite	11	15	13	14	16	15	12	14	13
Quartz	21	21	20	23	23	22	26	16	25
Amorphous	64	61	64	63	60	61	62	67	69
Others	4	3	3	–	1	2	–	3	3

The other phases present were corundum, anorthite, and zircon but these could not analyze quantitatively due to very low proportions. By comparing the data of Table 4 with Figures 5 and 6, it is found that Young's modulus and abrasion resistance were improved with increasing mullite content and deteriorated with increased amorphous phase content.

Table 5: Propeties of FAT 7 (30 wt % Fly Ash) in Comparison to EN Standards

Properties	EN Specification	Tiles of Composition
Water absorption (%)	<0.6	As per specification
Bending strength (N/mm2)	>30	30–38
Abrasion resistance (mm3)	<205	<150
Coefficient of thermal expansion (×10−6)	<9	As per specification
Thermal shock resistance	No alterations	As per specification
Moh's hardness	>5	7

Since the FAT7composition had shown the best properties compared to all other compositions, scanning electron microscopy of the fractured surface and optical microscopy of the polished surface of FAT7 composition fired at 1300^0C

was carried out. The Interlocked mullite and quartz crystals are embedded in the glassy matrix and dense microstructure is analyzed by a very small number of pores. Interlocked mullite and quartz crystals are embedded in glassy the matrix. The formations of needle-shaped clusters of crystals are also observed in pockets. EDX analysis revealed that these crystals are of mullite and quartz compositions. To study the suitability of these tiles for commercial application, a few 100×100×25 mm tiles of FAT7 composition (30% fly ash) were produced by firing in a roller kiln using a short firing cycle of 55 minutes. The properties of these tiles are shown in Table V. The European Nation (EN) standard specification values were also included in Table V for comparison. These tiles had better abrasion resistance, bending strength and hardness and conform to all other properties to EN specification.

CONCLUSIONS

The effect of fly ash additions on the properties of fly ash tiles has been studied. The bending strength of the green tiles was adversely affected by the additions; however, compositions of up to 30 wt% fly ash had sufficient strength for handling. The Young's modulus and abrasion resistance after firing was improved with fly ash additions and reached a maximum when 30 wt% fly ash was used. This is due to the formation of a dense microstructure consisting of a network of mullite and quartz crystals embedded in a glassy matrix. The reduction in strength for the tiles containing more than 30 wt% fly ash is due to increased glass phase content. A linear correlation between mullite formation and strength development was found. The tiles with 30 wt% fly ash confirm all the EN standard specification. Improved scratch hardness, bending strength and abrasion resistance were some of the added advantages besides a valuable use of a waste material.

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